

PERFORMANCE COMPARISON OF OPTICALLY PUMPED TYPE-II MID-INFRARED LASERS (Briefing Charts)

A.P. Ongstad, Ron Kaspi (AFRL)

G.C. Dente (GCD Associates)

M.L. Tilton, D.M. Gianardi, Jr., J.R. Chavez (Boeing LTS)

25 October 2005

Technical Paper

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.



**AIR FORCE RESEARCH LABORATORY
Directed Energy Directorate
3550 Aberdeen Ave SE
AIR FORCE MATERIEL COMMAND
KIRTLAND AIR FORCE BASE, NM 87117-5776**

REPORT DOCUMENTATION PAGEForm Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE (DD-MM-YYYY)
25 October 2005**2. REPORT TYPE**
Technical Paper Preprint**3. DATES COVERED (From - To)**
1 August 2004 - 7 July 2005**4. TITLE AND SUBTITLE**Performance Comparison of Optically Pumped Type-II
Mid-Infrared Lasers (Briefing Charts)**5a. CONTRACT NUMBER**
In-House (DF297213)**5b. GRANT NUMBER****5c. PROGRAM ELEMENT NUMBER**
63605F**6. AUTHOR(S)**A.P. Ongstad, Ron Kaspi (AFRL)
G.C. Dente (GCD Associates)
M.L. Tilton (Boeing LTS)
D.M. Gianardi (Boeing LTS)
J.R. Chavez (Boeing LTS)**5d. PROJECT NUMBER**
4866**5e. TASK NUMBER**
LY**5f. WORK UNIT NUMBER**
12**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)****8. PERFORMING ORGANIZATION REPORT NUMBER****9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**Air Force Research Laboratory
3550 Aberdeen Avenue SE
Kirtland AFB, NM 87117-5776**10. SPONSOR/MONITOR'S ACRONYM(S)****11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
AFRL-DE-PS-TP-2006-1002**12. DISTRIBUTION / AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

Briefing Charts for MIOMD Conference, Lancaster, England, 12 September 2005. GOVERNMENT PURPOSE RIGHTS: The U.S. Government has the right to use, modify, reproduce, release, perform, display, or disclose the work to authorize others to do so for U.S. Government purposes only.

14. ABSTRACT

We report a comparative study on the performance of three optically pumped, type-II quantum well lasers with differing quantum well confinement. One of the active regions emphasized hole confinement, another emphasized electron confinement, while the third incorporated both electron and hole confinement. In all cases the wells were inserted in a thick $\text{In}_x\text{Ga}_{1-x}\text{As}_y\text{Sb}_{1-y}$ waveguide/absorber region. The lasing wavelengths at 84 K were 2.26 μm , 3.44 μm , and 2.37 μm , respectively. The maximum peak output powers and differential quantum efficiencies, η_i , at 84 K were similar for the hole well and W lasers (≈ 13 W, $\eta \approx 0.55$), but significantly reduced in the electron well only laser (2.3 W, $\eta = 0.14$). Waveguide loss measurements via the traditional quantum efficiency vs. cavity length method and by a Hakki-Paoli method revealed that all three lasers had low waveguide loss that either increased slowly or not at all with increasing temperature. However, the laser's internal efficiency, η_i , showed a linear decline with increasing temperature, with the η_i of the electron well only laser significantly less than the other two. The data suggests that for antimonide based type-II designs, strong hole confinement is essential for improved performance. The data further suggest that it is hole leakage from the QW and/or hole dilution that is largely responsible for the degradation in laser performance.

15. SUBJECT TERMS

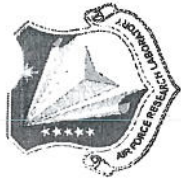
Antimonide, mid-infrared lasers, W laser, optically pumped semiconductor laser, quantum wells, waveguide loss, internal efficiency, gain, empirical pseudopotentials, hole leakage, hole dilution, thermal degradation

16. SECURITY CLASSIFICATION OF:**a. REPORT**
Unclassified**b. ABSTRACT**
Unclassified**c. THIS PAGE**
Unclassified**17. LIMITATION OF ABSTRACT**

Unlimited**18. NUMBER OF PAGES**

14**19a. NAME OF RESPONSIBLE PERSON**
Dr. Andrew Ongstad
19b. TELEPHONE NUMBER (include area code)
(505) 853-3207Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Performance comparison of optically pumped type-II mid-infrared lasers.



A.P. Ongstad, R. Kaspi

***Air Force Research Laboratory, AFRL/DELS
Albuquerque, NM USA***

DEPARTMENT OF THE AIR FORCE
SAF/PAX
CLEARED THIS INFORMATION

AUG 23 2005

FOR PUBLIC RELEASE

Clearance is granted for exact
content of viewgraphs only.

G. C. Dente

GCD Associates

M.L. Tilton, D.M. Gianardi, J.R. Chavez

***Boeing LTS,
Albuquerque, NM USA***

This is a
SAF/PAX document

05-0423

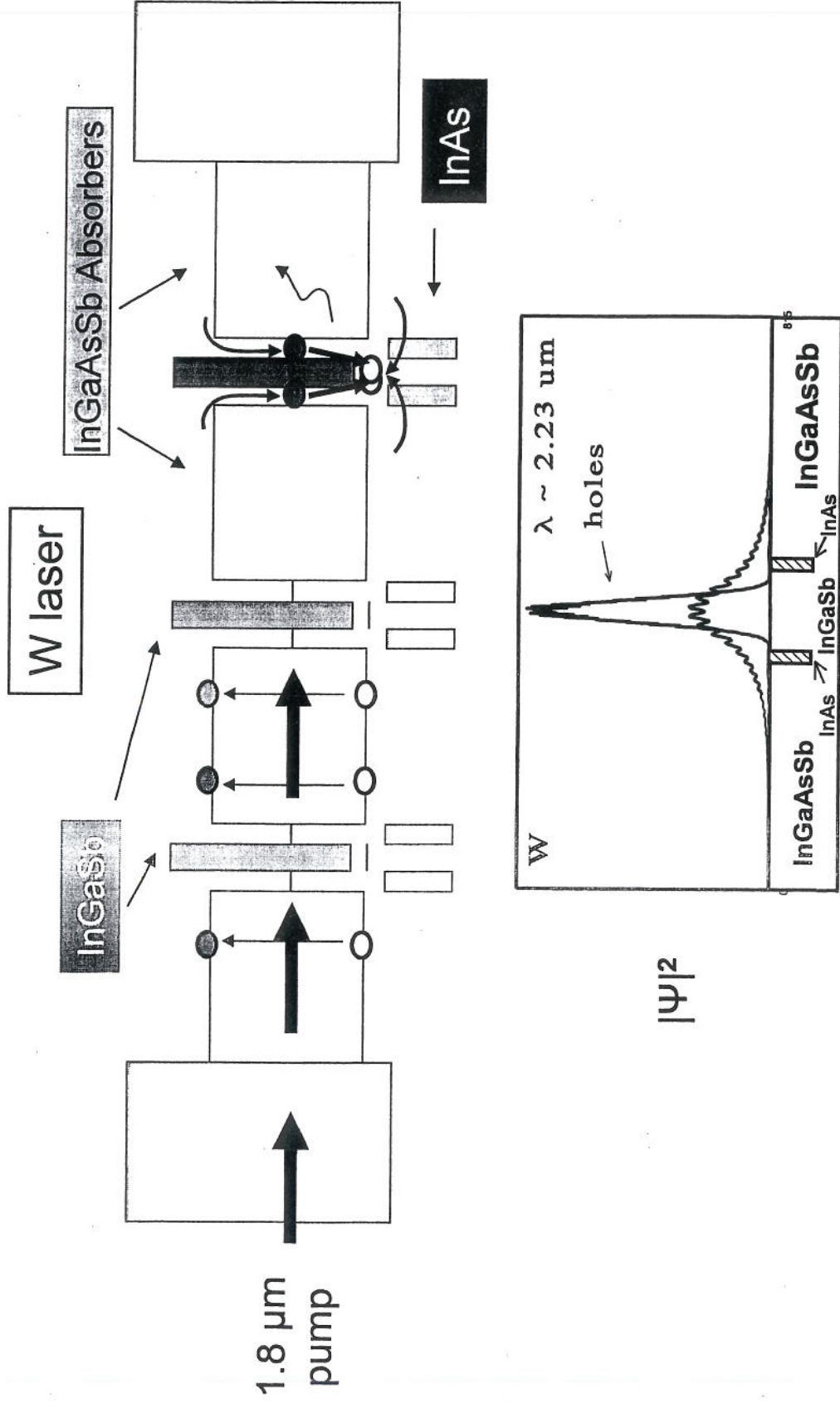
Call 697-0422 or 697-6715
For pickup or return to
4A120

AFRL/DE. 05-334

Objective

Compare performance of quantum well lasers with different carrier confinement.

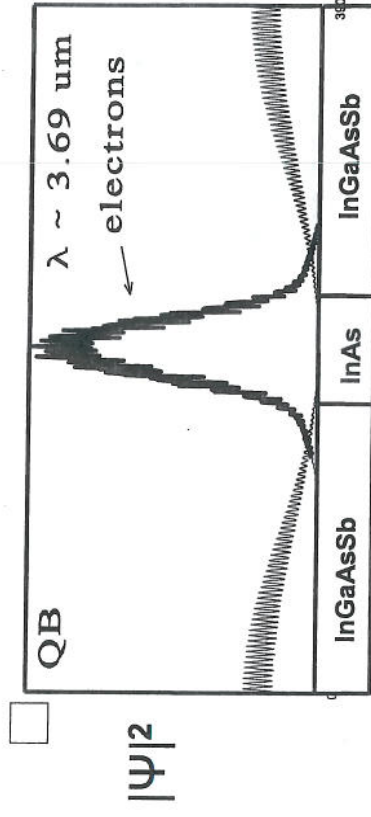
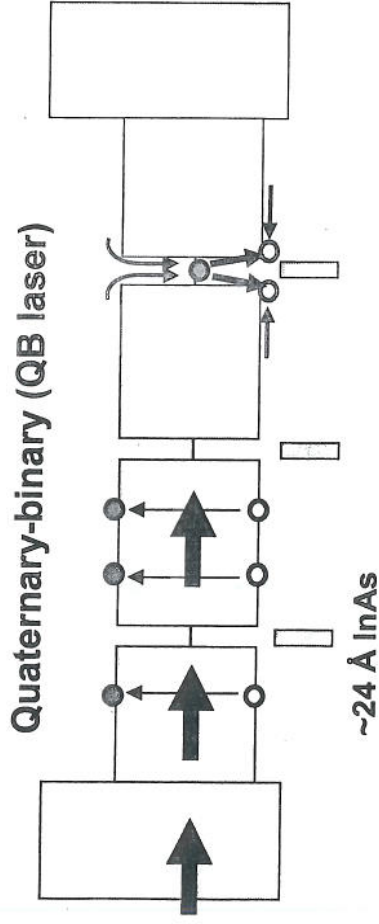
- 1) A $\sim 24 \text{ \AA}$ thick $\text{In}_{0.35}\text{Ga}_{0.65}\text{Sb}$ hole-bearing layer sandwiched by two thin InAs coupled electron wells. This is a W laser with both electron and hole confinement.



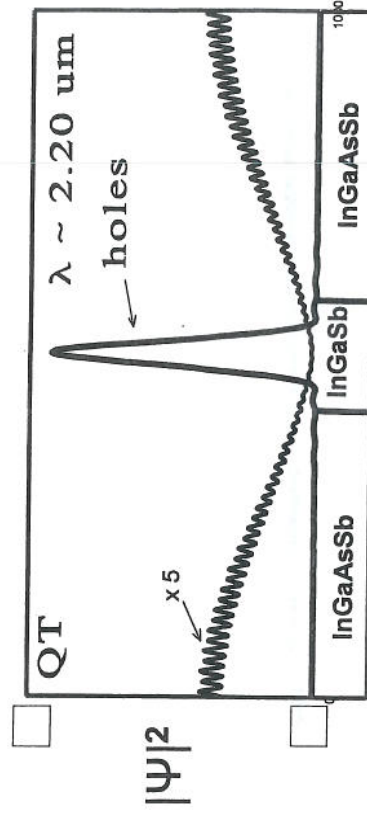
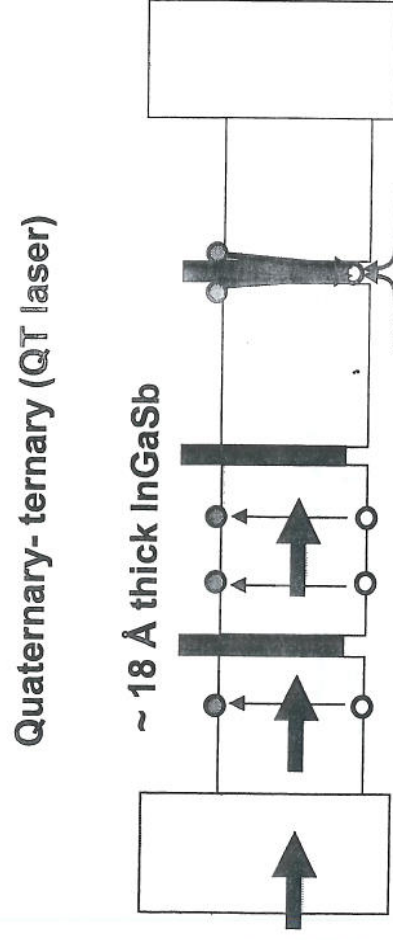
Objective:

Compare performance of quantum well lasers with different carrier confinement.

- 2) A ~ 24 Å thick InAs electron-bearing layer. This is a laser structure with *no deliberate hole confinement*.



- 3) A ~ 18 Å thick $\text{In}_{0.35}\text{Ga}_{0.65}\text{Sb}$ hole bearing layer. This is a laser structure with *no deliberate electron confinement*.



Spectra & peak output power at 84 K

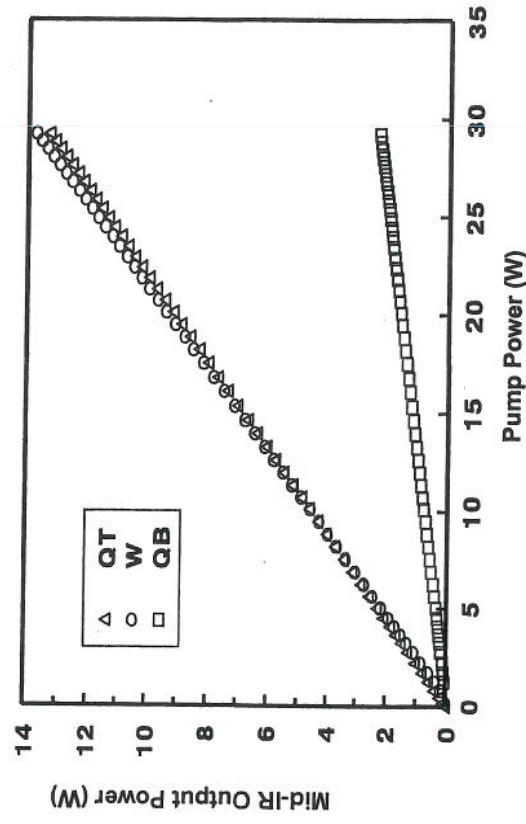
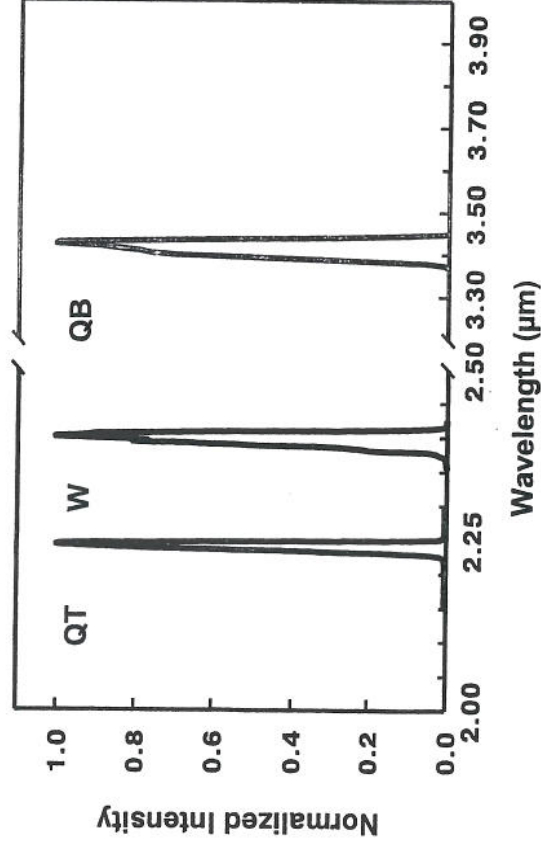
We observe significantly lower power output from the laser when the holes are not confined.

$$\lambda_{QT} = 2.26 \text{ } \mu\text{m}, P_{QT} = 13.3 \text{ W}$$

$$\lambda_{QB} = 3.44 \text{ } \mu\text{m}, P_{QB} = 2.3 \text{ W}$$

$$\lambda_W = 2.26 \text{ } \mu\text{m}, P_W = 13.7 \text{ W}$$

$$FW_{1/e}^2 \sim 5.3 \text{ meV}$$

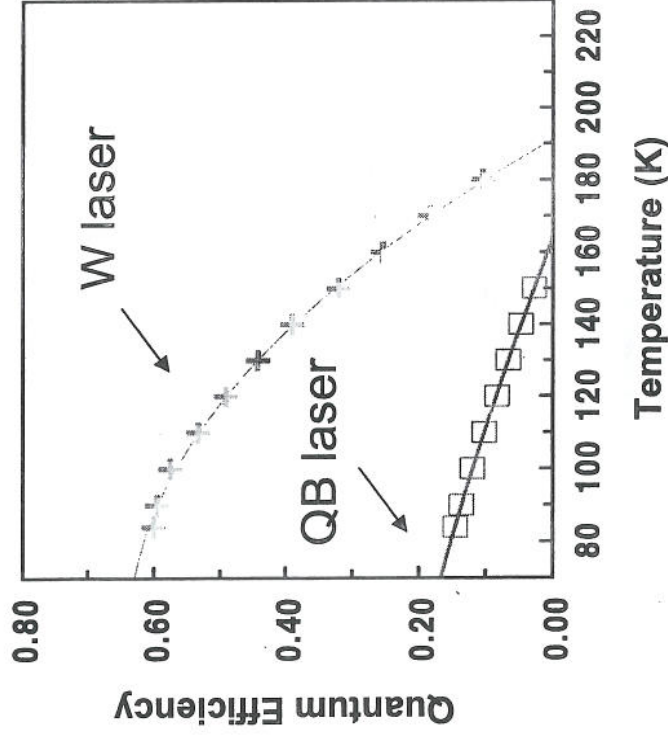


Confining electrons vs. confining holes.

We observe good high temperature operation when confining holes, but device performance is poor if only the electrons are confined. But why ?

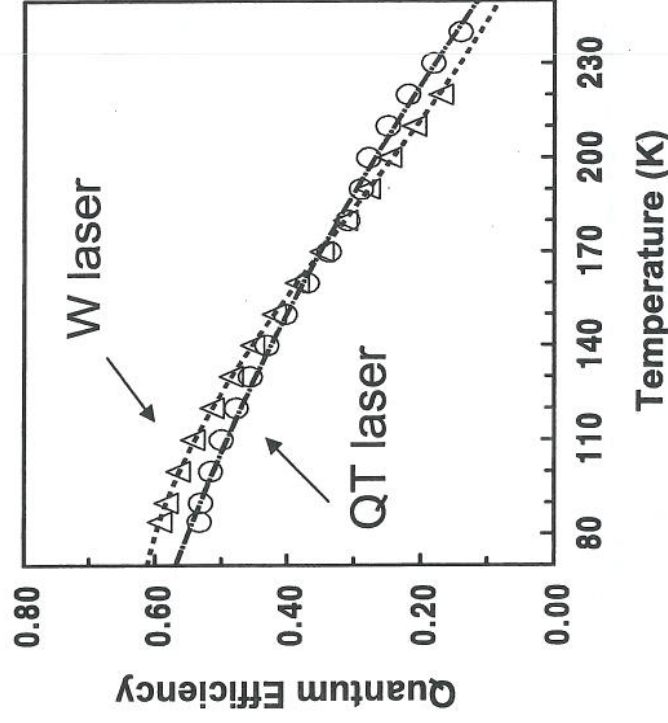
What if we only confine electrons ?

3.4 μm emitters



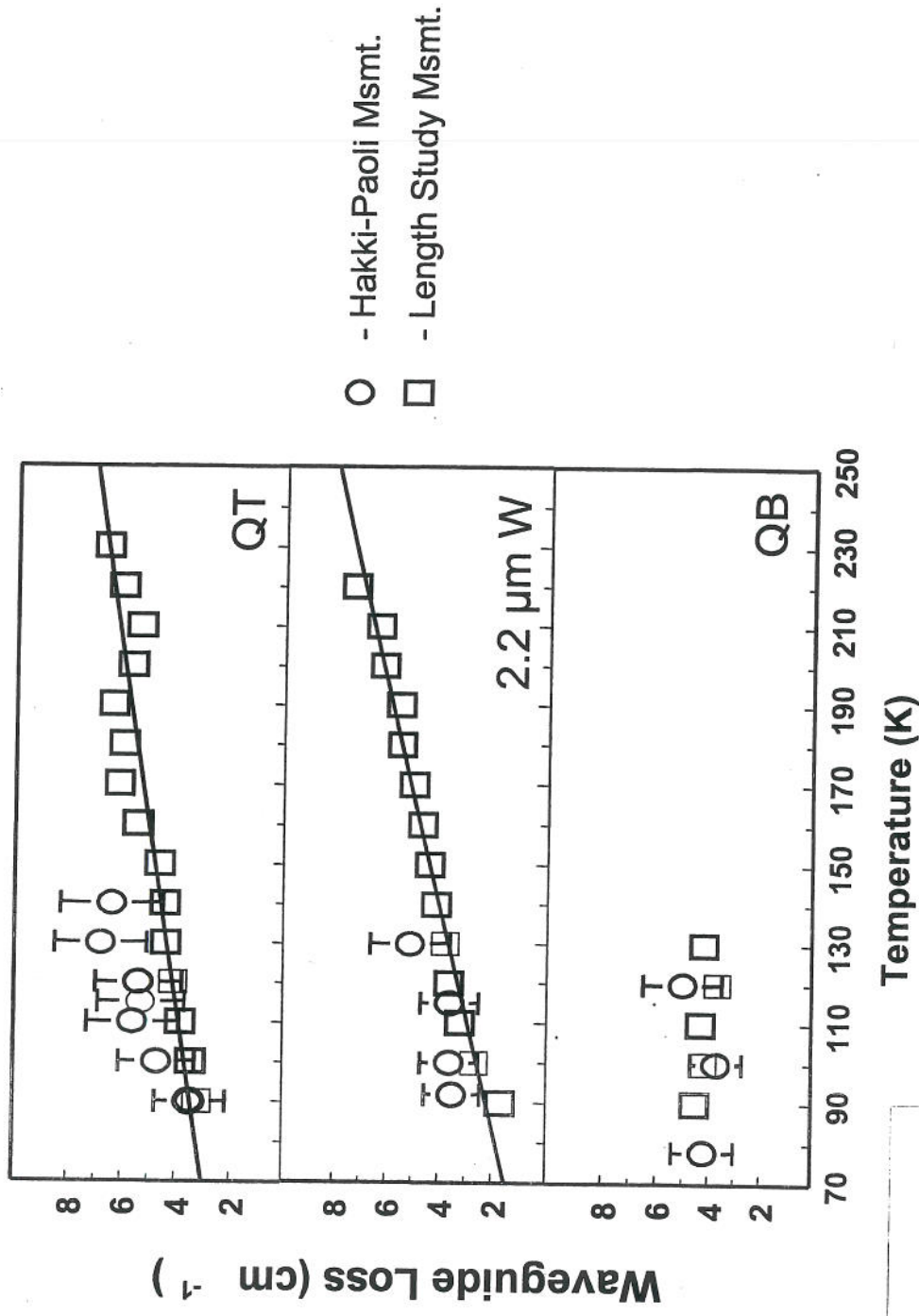
What if we only confine holes ?

2.2 μm emitters



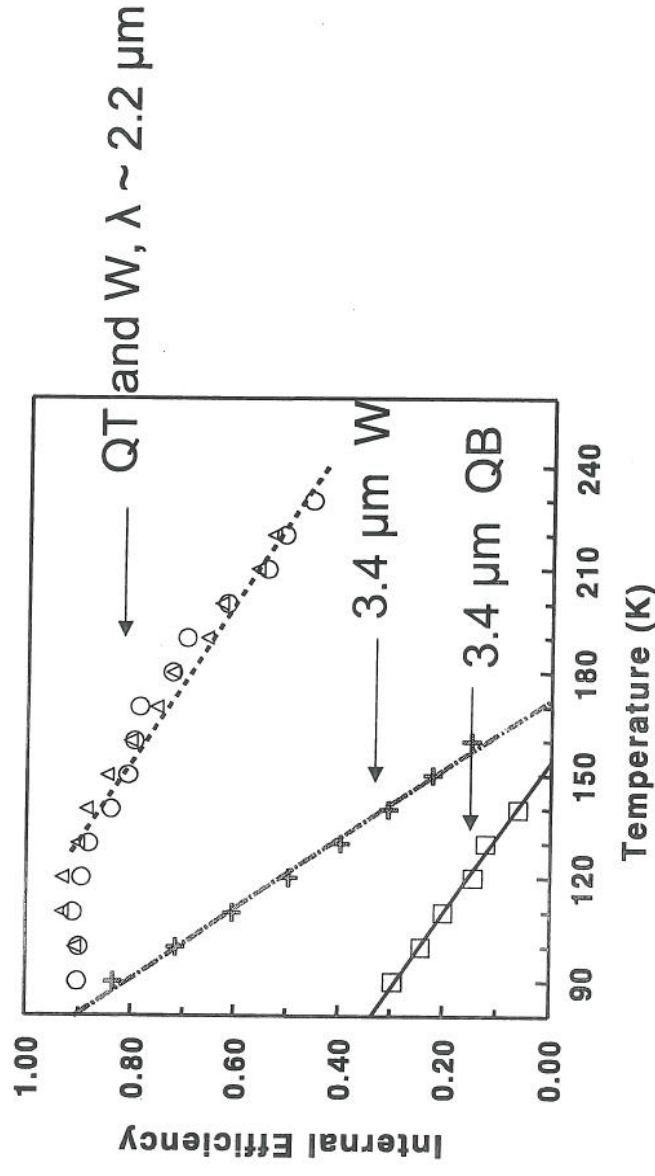
Does high waveguide loss account for the differences ?

No. We observe low waveguide loss and conclude degradation via intra-valence band absorbance and free carrier absorbance is small.



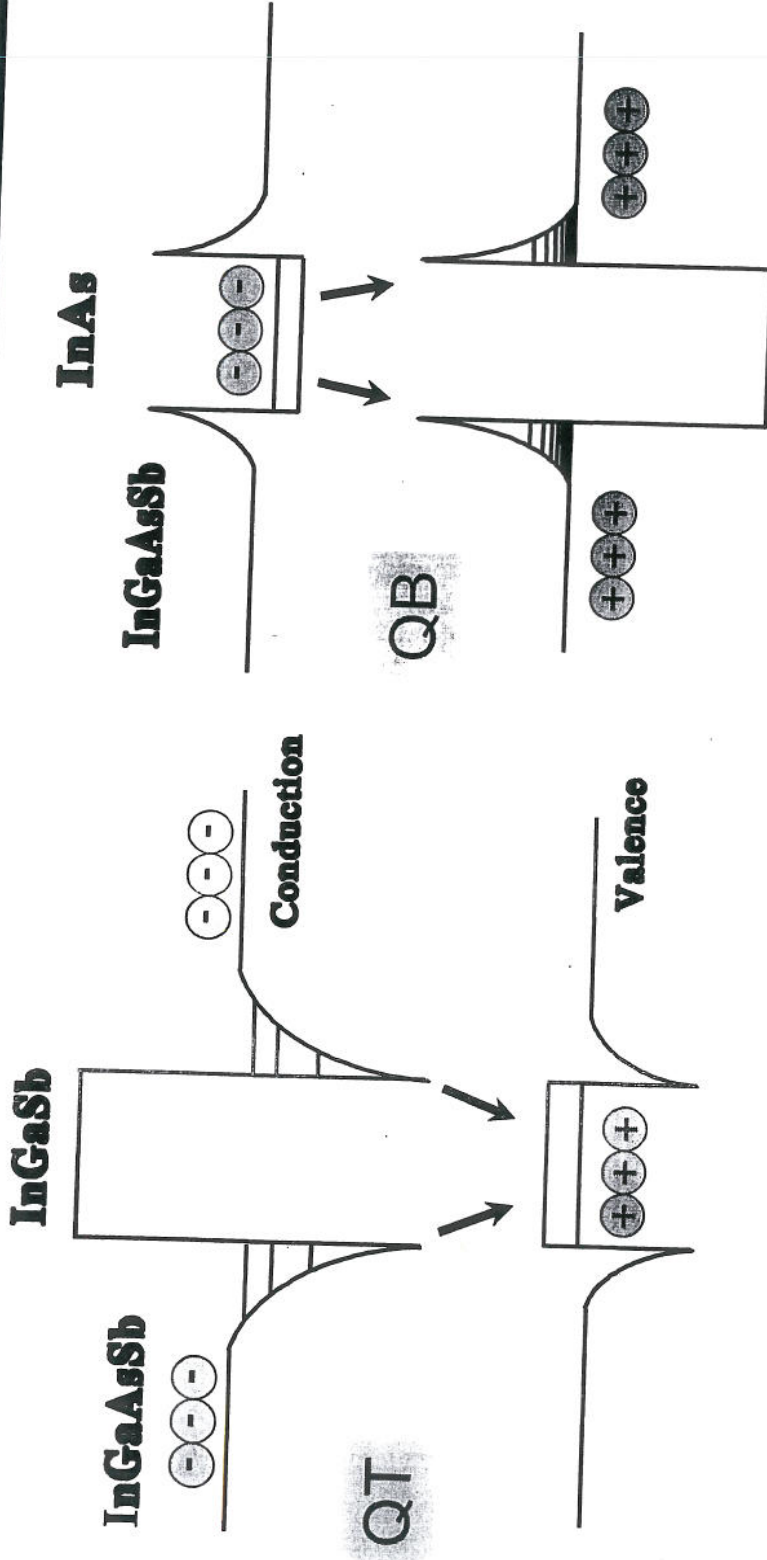
Does low internal efficiency account for the differences ?

Yes. We see an especially low internal efficiency for the QB. This suggests that the holes are not effectively used once generated.



- Comparison with 3.4 μm W laser shows that the poor η_i of QB laser is not solely due to the larger quantum defect.

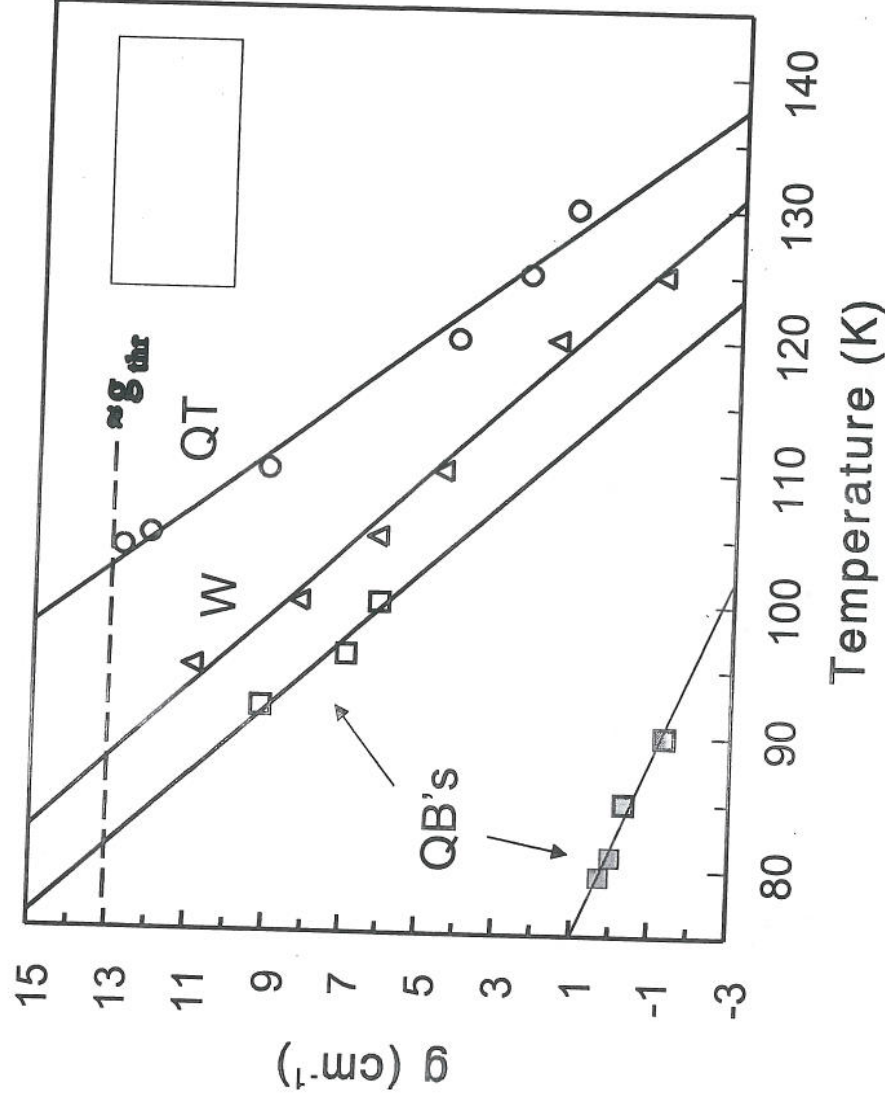
Why is the performance of the electron well laser so much worse than that of the hole well laser ?
Band bending occurs in each structure.



■ The effective hole mass is much greater than the effective electron mass ($m_h \gg m_e$) so the valence band states are much more densely packed near the band edge in the QB than are the conduction band states in the QT. Hence, in the QB, the gain is diluted over a much larger density of states.

Peak gain as a function of temperature at constant pump power.

The peak gain in the QB is diluted over a much larger density of states.

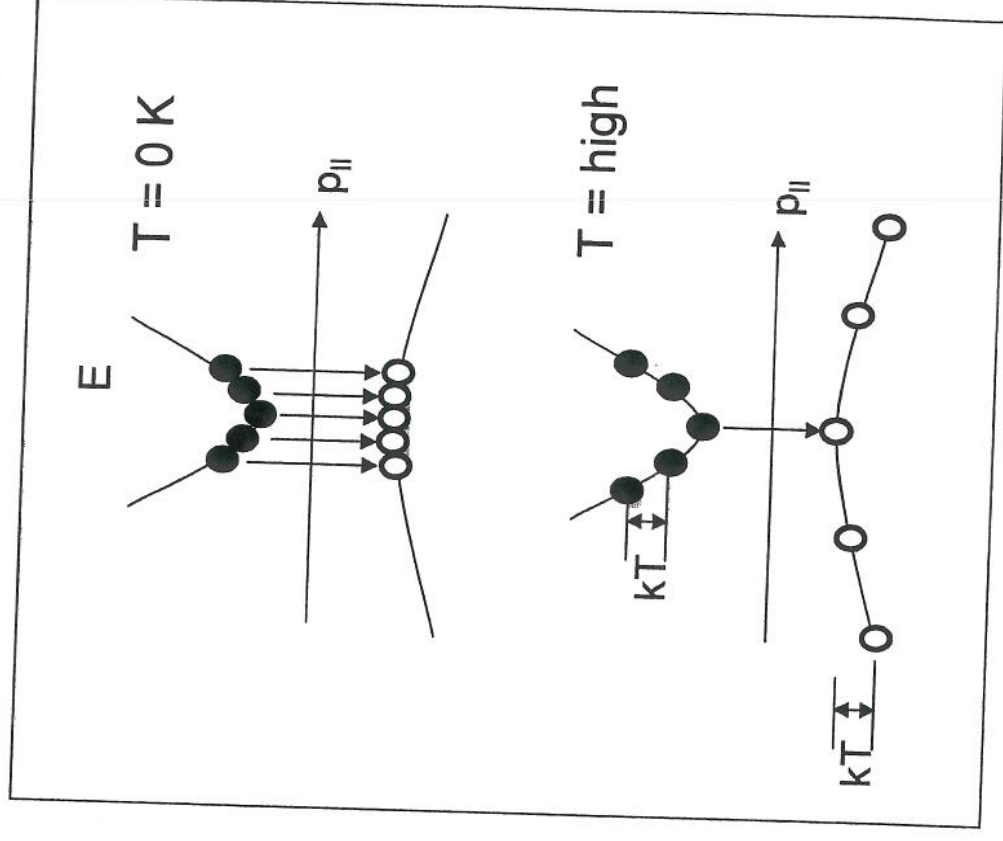
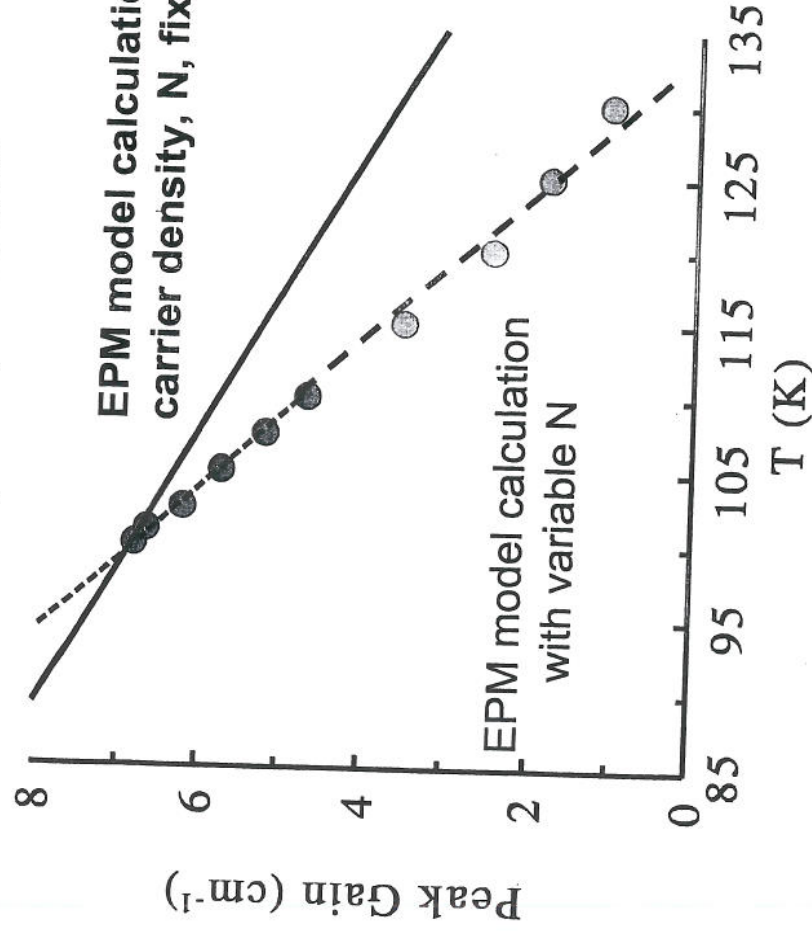


- 14 QW QB in a dilute waveguide; # QW's and waveguide equivalent to QT and W design
- 6 QW QB in a tight waveguide.

Superlattice empirical pseudopotential model (SEPM) prediction of gain vs. T at constant pump power.

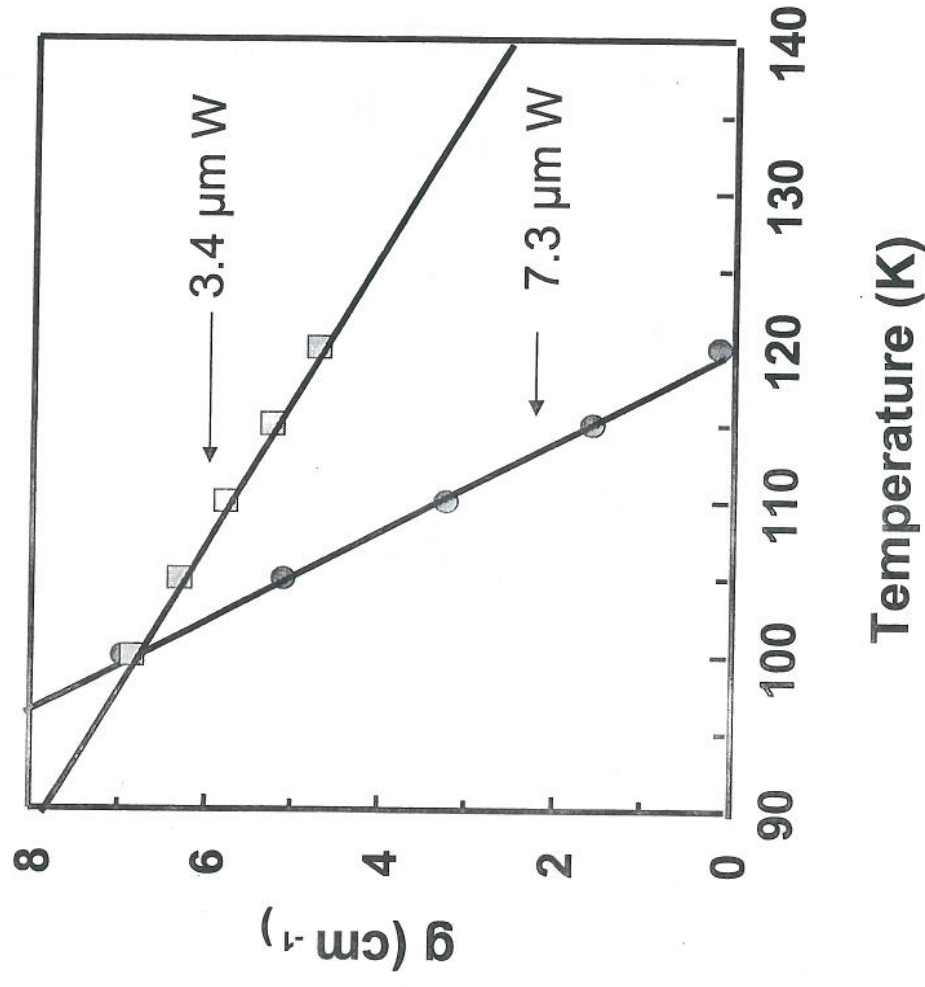
Momentum spread of holes accounts for much of the drop in gain in W-lasers.

- - Measurement on 3.4 μm W laser at constant pump power, ~ 865 mW.



SEPM predicts larger gain fall-off at longer λ operation.

Due to increased hole-dilution, more than one conduction band state being populated, and reduced hole transport.



Conclusions

Low waveguide losses were observed in W lasers, a hole well only laser (QT), and an electron well only laser (QB).

The decrease in quantum efficiency as temperature is increased is mainly due to a decrease in the lasers internal efficiency, η . This is partially due to the increased momentum spread of the holes at higher temperatures.

The poor η and low T_1 of the QB is due to the gain dilution incurred by the large density of valence-band states.

An effective hole quantum well is essential in producing a larger η . Without hole quantization or where the hole density of states is bulk-like, the performance is significantly degraded.